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Ecological effects of the microbial weathering of silicate minerals

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1 Introduction

Global climate change is one of the greatest challenges facing humankind in the 21st century. Studying, and utilising, the carbon sink caused by the weathering of silicate minerals has been a key research focus for scholars. The weathering of rocks, especially the chemical weathering of silicate minerals, consumes CO_2 by transforming CO_2 in the atmosphere or soils to HCO_3^- which is ultimately deposited as carbonate rocks in the oceans. This means that the weathering of silicate minerals is a net carbon sink, and has been across all time scales (Wofsy et al., 2001) and one which regulates and controls the amount of CO_2 in the atmosphere and the associated global climate change (Berner, 1995). The natural weathering of silicate minerals under physical and chemical actions is a slow, passive, process. Organisms, as one of the most active geological agents in the earth-surface system, especially microorganisms, can facilitate the weathering of silicate minerals. In the long-term course of geological evolution, the effect of microorganisms leads to the transfer of CO_2 in the atmosphere to carbonate rocks, forming the material basis of karst development and the largest carbon pool in the world (Lian et al., 2011). Weathering of silicate minerals by microorganisms is closely associated with their demand for mineral nutrients. In particular, microorganisms can drive the weathering of silicate minerals to release mineral elements in the environment with poor mineral nutrient levels by regulating their metabolic pathways, which is a physiological metabolism process used to obtaining mineral nutrients (Xiao et al., 2012a). Microorganisms can synthesise and secrete low-molecular-weight organic acids and facilitate the dissolution of minerals through acidification and complexion (Yao et al., 2013). The synergistic effect of some oxidoreductases and transport proteins also plays an important role in the biotransformation of minerals (Xiao et al., 2012b; Wang et al., 2015). Recent studies have found that the carbonic anhydrase (CA) of microorganisms which can promote the hydration of CO_2 in the atmosphere and is also involved in the biological weathering of silicate minerals and facilitates the formation of carbonate minerals (Xiao et al., 2012b; Sun et al., 2013). The biological weathering of silicate minerals can not only promote the release of mineral elements, but also form a secondary mineral, i.e., a carbonate mineral, thus showing certain carbon sink effects (Xiao et al., 2014; 2016a). The current research mainly introduces the potential ecological effects of the biological weathering of silicate minerals, in which the CA of microorganisms participates, and that of utilising the biological weathering of silicate minerals in the fertilisation of farmland.

2 Selective effects on microorganism CA

To reveal the extent of participation of microorganism CA in the biotransformation of minerals at different CO_2 concentrations, the effects of the CA of *Bacillus mucilaginosus* in the biological weathering of silicate minerals and the formation of carbonate minerals were investigated. The investigation was conducted at different CO_2 concentrations and under calcium ion stress using techniques including RT-qPCR, molecular cloning, heterologous expression of proteins, and protein purification. The results showed that the participation of CA exerted a more significant effect on the biological weathering of silicate minerals and larger proportions of carbonate minerals were generated at low CO_2 concentrations, compared with the effects of CA at high CO_2 concentrations. This indicates that the CA of microorganisms plays a more important role in the biological weathering and evolution of surface rocks at

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the currently low CO_2 concentrations (relative to those prevailing in ancient times) (Xiao et al., 2015). To study the selective effects of environment change on the CA isozyme, two CA genes of *Aspergillus nidulans* with clear genetic backgrounds were selected. Molecular biotechnologies including real-time quantitative PCR, heterologous expression, and northern blot analysis were utilised to reveal the expressions of the CA genes under culture conditions with different potassium sources (KCl or K-feldspar) and CO_2 concentrations (0.039 % or 3.9 %). In addition, the dissolution of calcite, biotite, and wollastonite, because of the CA with heterologous expression therein, were also studied. The results reveal that the two CA isozymes took part in different physiological activities. A CA gene was expressed as a priority to adapt to the change of CO_2 concentrations, while the expression of the other CA gene was associated with a scarcity of supply of mineral nutrients. Such selection, on the one hand, eases the adverse effects of environmental change (such as CO_2 concentration, and mineral nutrient supply, fluctuations) and avoids the waste of intracellular substances and energy on the other (Xiao et al., 2016b).

3 Increasing carbon sink effects by the biological weathering of K-feldspar

By carrying out experiments on potted *Amaranthus tricolor*, K-feldspar and dolomite minerals were added to poor soils to study whether, or not, their addition can increase the carbon sink effect in soils and the content of bio-available potassium and promote plant growth. In the experiment, the carbon content in the plant, the organic and inorganic carbon contents in the soil, and the amount of available potassium, as well as enzyme activities of polyphenol oxidase and urease, which can partially reflect the biochemical properties of the soil, were measured. The results suggested that the addition of the minerals can not only facilitate the fixation of organic and inorganic carbons in the soil, but is also able to improve the soil properties and facilitate the growth of the plant. Moreover, the addition of K-feldspar can increase the amount of available potassium in the soil to a significant extent (Xiao et al., 2016c).

Considering that the long-term use of mineral powders is likely to cause side effects such as soil desertification, organic waste and potassium-bearing mineral powders were used. Then, fermentation treatment was conducted through engineering approaches using specific probiotics and the resulting organic and mineral fertiliser was used in subsequent field experiments. A series of soil parameters (*e.g.*, pH, organic carbon content, microbial biomass, and amount of available potassium) were compared, as well as various indices describing water percolating through the soil including pH and bicarbonate concentration. The results of the comparisons indicated that the organic and mineral fertiliser can significantly improve soil properties and increase the potential carbon sink effect. In comparison, simply using chemical fertilisers was likely to acidify the soil and damage the structure of soil aggregates. A comprehensive analysis indicated that organic and mineral fertilisers can be partially substituted for conventional chemical fertilisers to promote plant growth, improve soil quality, and increase the carbon sink effect in soils (Xiao et al., 2017). The processes are related to the biological weathering effect of microorganisms in soils on potassium-bearing silicate minerals (Xiao et al., 2012b; Xiao et al., 2014; 2015) and have been found to be complicated (Wang et al., 2015). From the perspective of CA, the mechanism of participation of microorganisms in the biological weathering of silicate minerals and formation of carbon sinks is illustrated in Fig. 1.

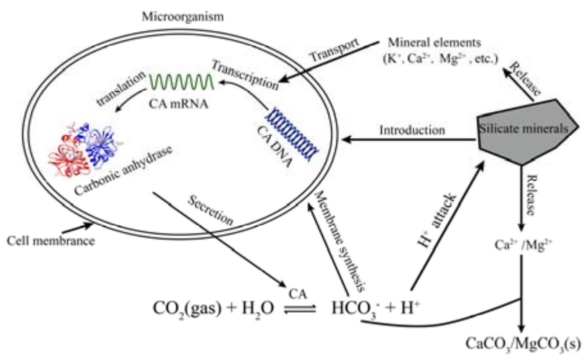

Fig. 1. The expression and mechanism of CA of microorganisms.

Due to the severe shortage of resources for water-soluble potassium-based fertilisers, using certain organic and mineral fertilisers as part-substitute for chemical potassium-based fertilisers is of great significance for China (as such a large agricultural producer). Apart from meeting the demands for chemical potassium-based fertilisers in some regions, it also avoids the adverse effects of soil acidification and environmental pollution arising from the use of large quantities of chemical fertilisers, thus exhibiting favourable ecological effects.

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